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Transient Power Quality Recognition Based on BP Neural Network Theory*

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Abstract

This paper researches on the combination between wavelet transformation and neural network to realize the transient power quality disturbance signals' recognition. Firstly, the mathematical models of five kinds of transient disturbance signals, such as voltage surging, voltage sag, voltage interruption, transient pulse and transient oscillation are founded. Then, using the nice time-frequency characteristic of wavelet, the sample signal's feature vectors are extracted. At last these feature vectors are input into BP neural network. Using the nice self-learning ability the disturbance signals can be classified and recognized. The examples show that the method has a higher discrimination. It's effective to resolve transient power quality problem.

Keywords: transient power quality problem, neural network, wavelet transformation, disturbance recognition

1.Introduction

Today transient power quality problems are becoming more and more important because of their more serious harm to the power system and power customers. Commonly the transient disturbance signals include voltage surging, voltage sag, voltage interruption, transient pulse and transient oscillation. Rapid detection and precise recognition on these disturbances is the basis for transient power quality problems resolving.

This paper will analyze the characteristics of wavelet transformer and neural network. Under Matlab environment a system for disturbance detection and recognition will be developed. In the system wavelet transform is used to extract the feature vectors of the disturbance samples, and the neural network tree is constructed to learn. Finally the tree is used to classify the power quality disturbance.

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2.The theory of neutral networks

The basic unit of neural network is neuron which is a nonlinear component with multiple-input and single-output. Neuron's universal structure model is shown in figure 1.

In the figure, u_i express inner state of neuron *i,* θ_i express established threshold value, x_i express input function, w_{ij} express weights connected to neuron x_i, s_i express an external input control signal.

Generally, a neuron model is described by a first order differential equation which can simulate the time-varying change law of synaptolemma's potential in biologic neural network.

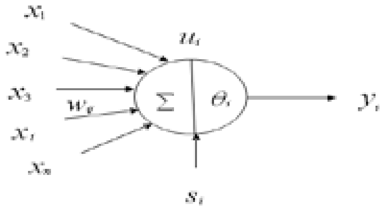

Fig1. Neuron's universal structure model

If the output of Neuron is expressed by function *f*, such a kind of functions can be used to express the non-linear feature of a neural network.

- threshold type, step function
- piecewise function
- S type function

The formula is shown as follows

$$f(u_i) = \frac{1}{1+\exp(-u_i/c)^2} \tag{1}$$

S type function has a feature that can reflect neuron's saturation. It is a continuous derived function. Through adjusting the parameters of it's curve, the similar threshold function can be gained. As a result of the feature, S type function is widely applied in the output of neural network.

Today more and more people like to use neural network to resolve the problems of fuzzy information process because of the network's too many nice features shown as follows.

- Neural network is nonlinear.
- Neural network can be distributed in parallel.
- Hardware for neural network founded is easy.
- Neural network has the ability of self-learning and self-adapting.
- Neural network support data fusion.
- Neural network is a multivariable system.

3.Transient Power Quality Recognition Based on BP Neural Network

3.1.Mathematical model of transient power quality disturbance signal

According to IEEE's definition on various types of power quality disturbances. Using algebraic equations in MATLAB, reference signals and test signals for five kinds of transient power quality disturbances such as voltage surging, voltage sags, voltage interruptions, transient oscillations, instantaneous pulse, can be randomly generated. The disturbance signals model are shown in Table 1, the simulation waveforms are shown in Figure 2.

TABLE 1 Transient power quality disturbance signal models

Disturbance type	Signal model	Parameter
Voltage surging	$u(t)=(1+\alpha(u(t_2)-u(t_1)))\sin(\omega_0 t)$	0.1~0.9, $T<\tilde{t}_2 t_1<9T$
Voltage sag	$u(t)=(1-\alpha(u(t_2)-u(t_1)))\sin(\omega_0 t)$	0.1~0.9, $T<\tilde{t}_2 t_1<9T$
Voltage interruption	$u(t)=(1-\alpha(u(t_2)-u(t_1)))\sin(\omega_0 t)$	0~0.1, $T<\tilde{t}_2 t_1<9T$
Transient oscillation	$u(t)=\mathbf{sin}(\omega_0 t)+\alpha * e^{-c(t-t_1)}\cdot\mathbf{sin}(\beta\omega_0(t-t_1))\cdot(u(t_2)-u(t_1))$	0.1~0.8, 10~1000 c 5000~10000, 0.5 $T<\tilde{t}_2 t_1<2T$
Transient pulse	$u(t)=(1-\alpha(u(t_2)-u(t_1)))\sin(\omega_0 t)$	>0.414, T 20< $\tilde{t}_2 t_1<T/10$

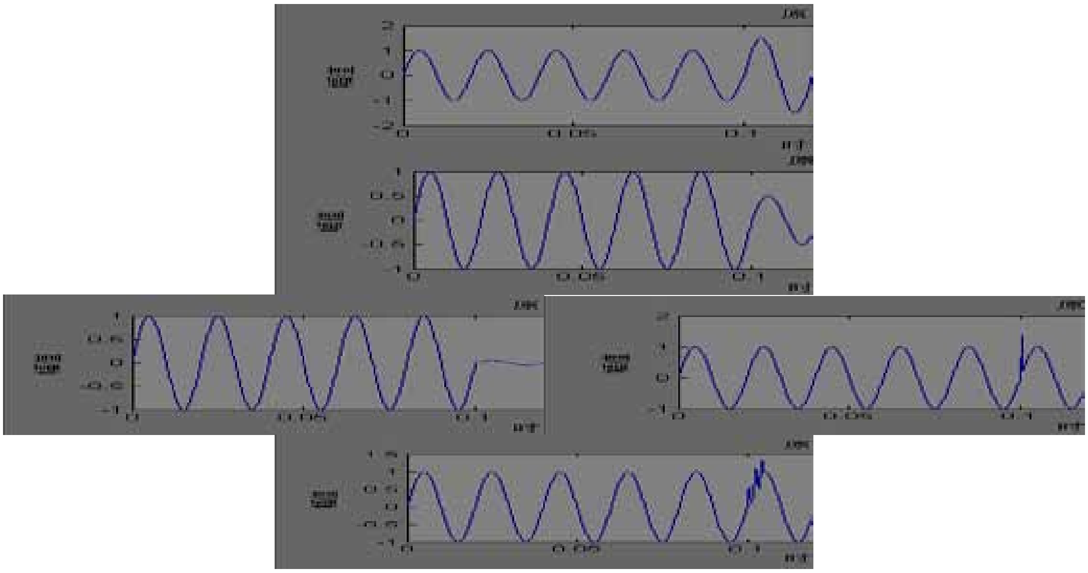
Fig 2 Five kinds of waveforms of transient power quality disturbances

3.2.Feature Extraction

Each frequency band component of the simulative transient power quality waveform is deferent. Because the Fourier analysis can only process frequency domain problem, and can't process time domain problem, it is not suited to resolve transient quality problems. But wavelet transform has the function of multi-resolution analysis, it can combine the time domain information with the frequency domain information to describe the waveform's time-frequency spectrum. So wavelet transform method is a good way to analyze transient disturbance. It can be used to decompose transient power quality disturbance signals, seize disturbance information, and realize disturbance features extraction.

Now we use db3 wavelet basis to do 3 layers wavelet decomposition. Then one low frequency coefficient and three high frequency coefficients will be extracted. Calculating all the coefficients' energy values, arraying the coefficients into a column of vectors according their values, the vectors express the disturbance features.

Wavelet energy in subspace of the tested signal *f(t)* can be defined as follows.

$$EW_j = \int \left| S3_j(t) \right|^2 dt = \sum_{k=1}^{n} \left| d_k^j \right|^2 \tag{2}$$

Specific measures are shown as follows：

① Running 3 layer decomposition to the output disturbance sample signal, wavelet decomposition coefficients of the four frequency band can be gained. Reconstructing each node wavelet decomposition coefficient, the total signal S can be expressed as follows.

S=A3+D3+D2+D1

② Calculate the total energy of all the decomposition coefficients. Suppose that $E_{(3,j)}$ $(j = 0,1,2,3)$ express the corresponding energy of $S_{(3,j)}$ $(j = 0,1,2,3)$, then

$$E_{(3,j)} = \int \left| S3_j(t) \right|^2 dt = \sum_{k=1}^{n} \left| x_{jk} \right|^2 \tag{3}$$

The symbol of x_{jk} $(j = 0,1,2,3,4 \mathrm{k} = 1,2,\ldots\ldots,\mathrm{n})$ expresses each discrete point's amplitude of the reconstructed signal of $S_{(3,j)}$.

③ Construct feature vectors. Feature vector T constructed as follows:

$$T = [E_{(3,0)}\, E_{(3,1)}\, E_{(3,2)}\, E_{(3,3)}] \tag{4}$$

When the energy is large，$E_{(3,j)}$ $(j = 0,1,2,3)$ usually is a relatively large value, and data analysis will be inconvenient. Therefore, the feature vector T should be given normalization processing. Shown as follows

$$E = (\sum \left| E_{(3,j)} \right|^2)^{1/2} \tag{5}$$

$$T' = [E_{(3,0)}/E \quad E_{(3,1)}/E \quad E_{(3,2)}/E \quad E_{(3,3)}/E] \tag{6}$$

T' is the normalization vector。

3.3.Power quality disturbance classification based on the BP neural network

BP network is a kind of multilayer forward network with mono directional transmission. The network usually has three layers, including input layer, hidden layer and output layer. Although the three layers are connected together, but the neurons in the same layer do not connect to each other. When some samples are put into input layer, the neurons are activated. The active values are transmitted from input layer to hidden layer, and then from hidden layer to output layer. The neurons in output layer get the network's input response. And then, for reducing error amount between objective output and actual one, each connective weight will be corrected from output layer to hidden layer and to input layer. The algorithm is called "Error BackPropagation Method", that is to say BP algorithm. Along with repeating correction to the backpropagation errors, the accuracy rate of the network 's response to the input are rising continuously. The specific flow of power quality disturbance classification based on BP neural network is shown as follows.

- Establishing training database and testing database

Training data and testing data should be simultaneously constructed for momentarily drawing off. The data samples are produced according to the disturbance mathematical models, their parameters are selected according to the statistical rule. One part of the samples is randomly selected to be training data, and the others become testing data.

- Normalizing Data

Data Normalization refers to normalize the input data into a small range, generally into the range of (-1 1) or (0 1). On one hand the normalization can prevent over-training caused by large range data. On the other hand it can avoid the too big data which is hard to express in the calculation process.

- Defining structure and parameters of BP network

According to KOLMOGOROV theorem，a $N \times (2N+1) \times M$ three layers BP network is used as a state identifier. In the network, N expresses component value of the input feature vector, M expresses total numbers of output state classification. In the test, N = 5, M = 3. To simplify the neural network structure, (0,0,0) expresses voltage surging, (0,0,1) expresses voltage sag, (0,1,0) expresses voltage interruption, (0,1,1) expresses instantaneous pulse, (1,0,0) expresses transient oscillations. It means that the five kinds of transient disturbance only need three output neurons. So in the structure of the BP network there are 5 neurons in input layer, 11 neurons in hidden layer, and 3 neurons in output layer. Because the range of input vector is (0 1), the transfer function of the hidden neuron can be the S type tangent function.

- Training BP neural network

Functions are used to train BP neural network, make the network has the function of classification. Different training functions bring different velocity of convergence.

- Classifying Disturbances

Input test data, and use the trained model to get classified result.

4.Example analysis

In the process of the classification, training by different function will get different results. In this research we use three kinds of training solutions.

In the first solution, the function TRAINGDX was used to train the BP network. The function's algorithm is called gradient descent with momentum algorithm. It's learning be self-adaptive.

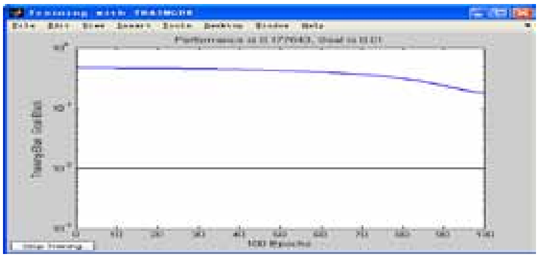

Fig 3 the first solution training process

In the second solution, the function TRAINLM was used to train the BP network. The function's algorithm is called Levenberg_Marquadt back propagation algorithm. It has a higher speed of convergence.

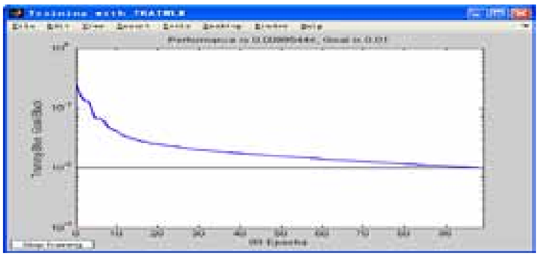

Fig 4 the second solution training process

In the second solution, the function TRAINGD was used to train the BP network. The function's algorithm is just a kind ordinary gradient descent algorithm.

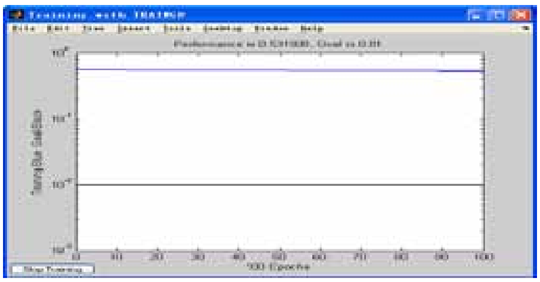

Fig 5 the third solution training process

According to the compare among the three train function, a conclusion is that the function TRANLM is quick and precise. Finally we select it to construct the BP network. The main program codes in MATLAB are shown as follows.

```
T=[0 0 0;0 0 0;0 0 0;0 0 0;0 0 1;0 0 1;0 0 1;0 0 1;0 1 0;0 1 0;0 1 0;0 1 0;0 1 1;0 1 1;0 1 1;0 1 1;1 0 0;1 0 0;1 0 0;1 0 0];
P=P';T=T';
net=newff(minmax(P),[11,3],{'tansig','logsig'},'trainlm');
net.trainParam.epochs=1000;
net.trainParam.goal=0.01;
net=train(net,P,T);
```

The test data is shown in table 2, the serial number 1 to 5 respectively represent voltage surging, voltage sag, voltage interruptions, transient pulse and transient oscillation. The classification results are shown in table 3 to 6 in which the samples number increase from 50 to 250. Seen from the results tables, the classification rate is very higher.

TABLE 2 test data

sn	State data	Disturbance type
1	0.9995 0.0262 0.0159 0.0125	voltage surging
2	0.9995 0.0251 0.0162 0.0129	voltage sag
3	0.9982 0.0318 0.0401 0.0325	voltage interruption
4	0.9920 0.0491 0.0899 0.0735	transient pulse
5	0.9980 0.0343 0.0455 0.0257	transient oscillation

TABLE 3 Classify Results of 50 samples

Category	Sample numbers	Un-identified numbers	Classification rate
Voltage surging	10	0	100%
Voltage sag	10	0	100%
Voltage interruption	10	0	100%
Transient pulse	10	0	100%
Oscillatory transient	10	0	100%

TABLE 4 Classify Results of 150 samples

Category	Sample numbers	Un-identified numbers	Classification rate
Voltage surging	30	1	97%
Voltage sag	30	1	97%
Voltage interruption	30	0	100%
Transient pulse	30	0	100%
Oscillatory transient	30	0	100%

TABLE 5 Classify Results of 200 samples

Category	Sample numbers	Un-identified numbers	Classification rate
Voltage surging	40	1	97.5%
Voltage sag	40	1	97.5%
Voltage interruption	40	1	97.5%
Transient pulse	40	0	100%
Oscillatory transient	40	0	100%

TABLE 6 Classify Results of 250 samples

Category	Sample numbers	Un-identifie d numbers	Classification rate
Voltage surging	50	2	96%
Voltage sag	50	1	98%
Voltage interruption	50	1	98%
Transient pulse	50	0	100%
Oscillatory transient	50	0	100%

5.Summarize

In this paper, wavelet and BP neural network are used to defect and classify five kinds of transient power quality disturbance. The wavelet deverses the disturbance’s detection, and the BP neural network deserves the disturbance’s classification. A lot of tests have proved that the combination of the two method is useful, it can be used to resolve the transient power quality problems. Of course, more research work must be done in use of the neural network, especially include the convergence velocity’s increasing and the hidden function’s rapidly selection.

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